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The Naval Research Laboratory

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MATERIALS SCIENCE & TECHNOLOGY DIVISION

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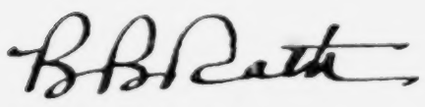
PROFILE

The Division of Materials Science and Technology is central to the multidisciplinary research in the field of materials science at the Naval Research Laboratory. The branches conduct fundamental research to understand the basic behavior of matter and the exploratory development of new, engineered materials to meet Naval needs. In our fast changing technological world, there is always a need for highly qualified and innovative individuals to conduct leading-edge research and contribute to future technologies.

The following pages provide a brief introduction to the areas of research conducted in the Materials Science and Technology Division (MS&TD) along with the names of key supervisory scientists and selected state-of-the-art research facilities. Those qualified in this broad field of research and interested in a career in materials science at NRL are urged to contact Mr. R. W. Judy, Associate Superintendent, (202) 767-2540, for additional information and an employment application.



B. B. RATH
Associate Director of Research
Materials Science and
Component Technology Directorate

COVER

The photographs illustrate major research areas in the MS&TD. Top: a magnet being levitated above a ceramic superconductor that is maintained at a temperature of 77 K; center: a composite formed from Nb fibers in a copper matrix; lower left: the stress distribution in an axially loaded test piece; lower right: a plasma formed by the interaction of a larger beam with the surface of a metallic material.

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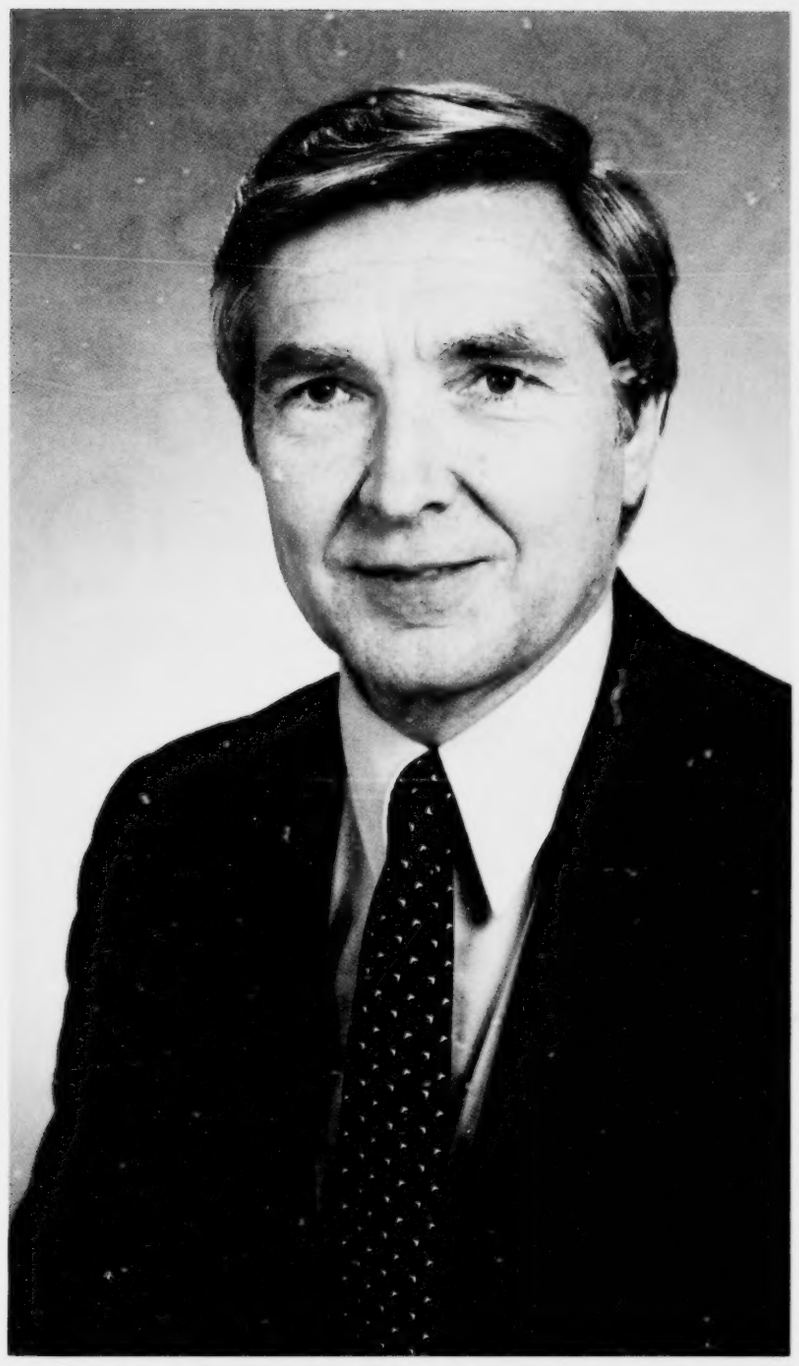
MESSAGE FROM THE SUPERINTENDENT



Donald U. Gubser
Ph.D. in Physics
University of Illinois

The world is entering a new materials age with unprecedented technological advances on the near horizon. Examples of this can be cited in almost every scientific field.

- In superconductivity, new ceramic oxides have increased by an order of magnitude the temperatures where electrons flow in a resistanceless manner, making seemingly science-fiction technology a scientific reality.
- In magnetism, the coercive force has also been increased by an order of magnitude, creating inexpensive materials that promise to revolutionize many technologies.
- In electronics, miniaturization is leading to complex, multicomponent devices involving integration of many materials systems, thereby leading to quantum-limited sensitivities with wide-ranging applications.
- In materials synthesis and processing, advances in technology now permit ultrarapid cooling, which can preserve metastable compositions and structures (amorphous, crystalline, or quasicrystalline) with new and improved properties.
- Heterogeneous materials (composites, multiphase, multilayer, multiparticle) are providing performance not previously achievable in areas such as high

(Continued)

temperature aerospace applications or acoustic and electromagnetic damping.

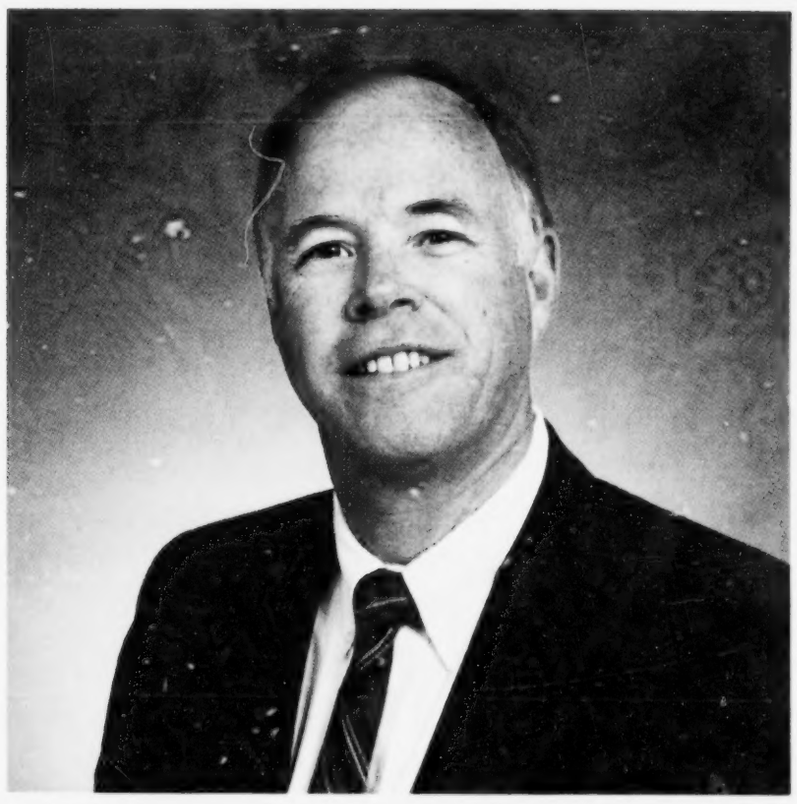
- In structural materials, composites of a variety of materials (ceramics, organics, metals) are leading to ultrastrong, lightweight materials that can be tailored to uniquely fit specific applications.

- Our theoretical and computational capabilities have reached the stage where we can often predict properties and responses of materials before their actual fabrication.

Driving this materials revolution are advances in our abilities to manipulate and analyze materials at atomic and microstructural levels and our increasingly sophisticated computational capabilities, which permit us to predict the response of a totally integrated materials system, not just its individual components.

The field of materials science is truly a multidisciplinary area that combines some of the most exciting science in the fields of chemistry, physics, electronics, and mechanics. The MS&TD strives to maintain this multidisciplinary approach in its research and development programs, which are varied in scope—from the most fundamental materials research to research of a more applied nature. The synergism of these programs leads to a very effective materials science and technology program at NRL that is responsive to the Navy's needs of today and—most importantly—of tomorrow. As we move forward into the 21st century, materials science and technology will play an increasingly important role in shaping the Navy's ability to respond to national defense needs.

KEY PERSONNEL



Ralph W. Judy, Jr.
Associate Superintendent

S. Ann McIntire
Administrative Officer

The MS&TD has 140 full-time employees in four interacting scientific branches and one functional group. The key personnel are listed below:

Name	Title	Code	Phone (Area Code - 202)
Dr. D.U. Gubser	Superintendent	6300	767-2926
Mr. R.W. Judy, Jr.	Associate Superintendent	6301	767-2540
Mrs. S.A. McIntire	Administrative Officer	6302	767-2113
Dr. C.R. Crowe	Head, Physical Metallurgy Branch	6320	767-2465
Dr. S.A. Wolf	Head, Material Physics Branch	6340	767-2600
Dr. S.C. Sanday	Head, Composites and Ceramics Materials Branch	6370	767-2264
Mr. E.D. Thomas	Head, Marine Corrosion Facility	6370.1	(305) 296-3546
Dr. R. Badaliance	Head, Mechanics of Materials Branch	6380	767-6380

PHYSICAL METALLURGY BRANCH

The branch's work is directed toward understanding unique metallic materials by controlling phase transformation, microstructure, and atomic order. We study fundamental mechanisms associated with basic phenomena in metals and alloys. The influences of microstructure and defects—such as vacancies, dislocations, internal interfaces, and impurity atoms—are correlated with mechanical, electrochemical, electrical, and thermal properties. Typical programs include:

Microstructure. Specific efforts are aimed at modeling phase-transformation kinetic behavior and characterizing the microstructure of materials. Models of grain growth, precipitation nucleation, and twinning mechanisms are currently under study.

Environmental Effects Research. The mechanisms of corrosion and development of new techniques—such as ion implantation and ion-assisted deposition to improve corrosion resistance—are current topics of study. The effects of hydrogen on material properties and the effects of elevated thermal exposure on mechanical properties are also being studied.

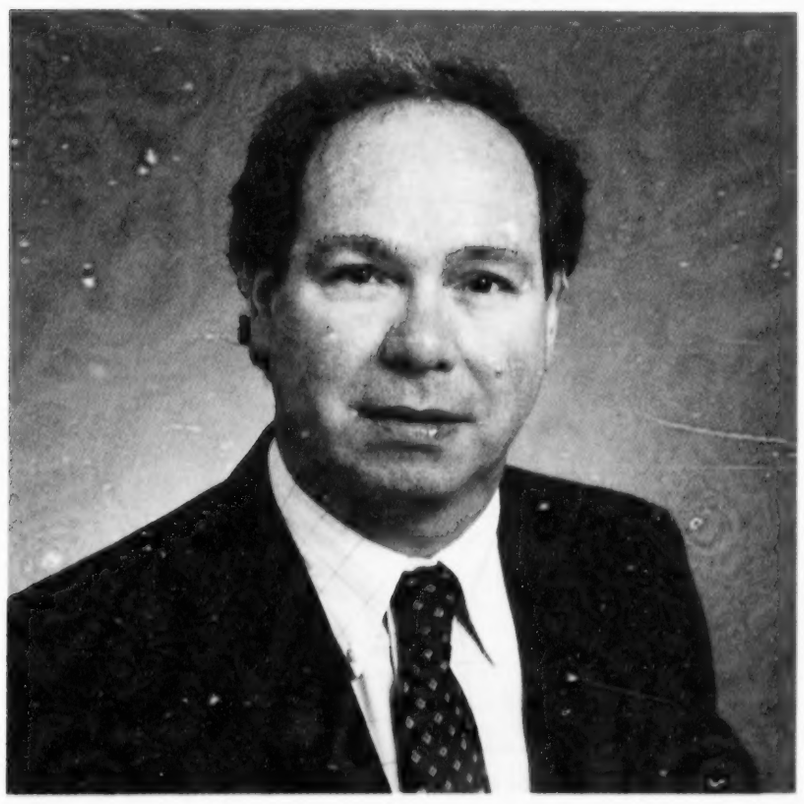
Mechanical Behavior. Theoretical and numerical methods to predict the dynamic response of advanced materials subjected to extreme thermal and mechanical environments are developed and applied.

Fatigue Initiation and Propagation Mechanisms. Materials include titanium, aluminum, and steel alloys.

Optimization of Cracking Resistance. Studies include advanced structural materials for naval aircraft.

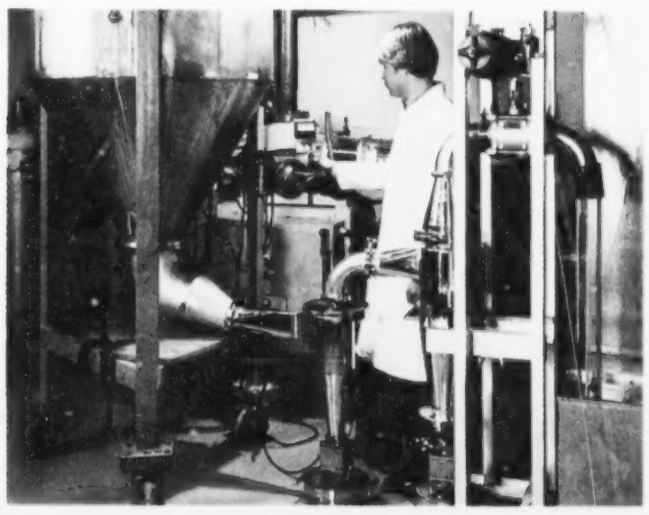
Corrosion Fatigue. Emphasis is on the effects of microstructure on fatigue crack growth behavior in seawater.

Ripple Load Effects on Stress Corrosion Cracking. Emphasis is on high-strength, low-alloy (HSLA) steels.



Robert Crowe
Ph.D. in Materials
University of Maryland

"It's an exciting time to be working in materials science. Many revolutionary breakthroughs are occurring, and I am fortunate to be a part of them."



Ultrasonic Gas Atomization Facility is used to produce very fine metal powder. Molten metal is forced through fine orifices by gas pressure into a cooler quenching gas steam, to produce spherical particles of metal powder.

Ordered Intermetallic Alloys. Emphasis is placed on developing new, high-temperature materials for use in advanced aerospace systems, such as the National Aerospace Plane and advanced jet engines. A major thrust involves work on the gamma phase titanium aluminides and their composites, but other intermetallic alloys are also being studied.

Innovative Processing. Techniques to develop new materials and processes, such as nano-sized material, rapidly solidified powders, laser processing, and new joining methods, are studied to improve materials for future use. Current efforts in this area are in welding, diffusion bonding, rapid solidification of powders, and development of innovative composite fibers.

Applied Research. In direct support of the Fleet, many projects involve developing processes for improving component performance and performing failure analyses. Efforts in these areas are directed toward improving the superalloy turbine blades used in jet engines and turbine blade repair. Failure analyses are varied.

FACILITIES

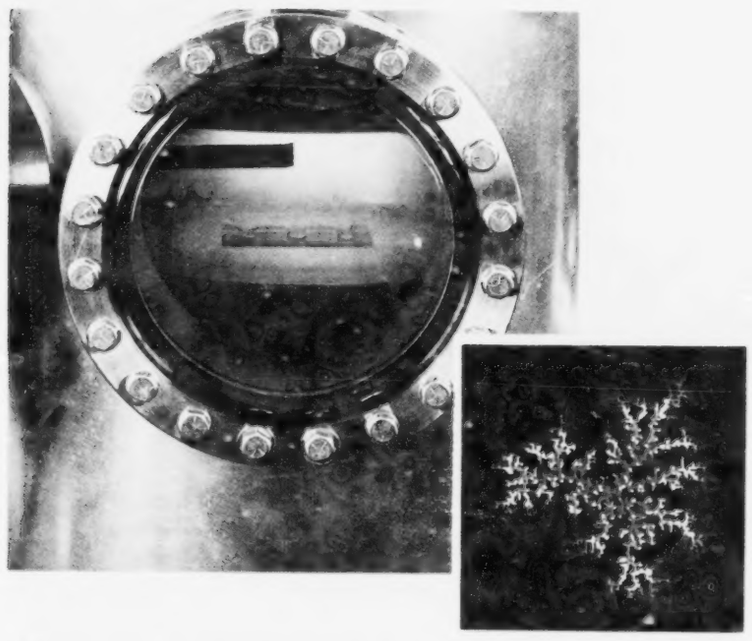
- Rotating and ultrasonic gas atomizers
- Consumable arc-electrode melter
- High-energy dispersive X-ray analytical system
- X-ray spectrograph fluorescence
- Vertical and horizontal servo-hydraulic testing machines with automated data acquisition and control
- Automated data acquisition and control systems with "spectrum" capability
- Complete modern electron microscope facilities
  - — Electron microprobe
  - — TEM
  - — STEW
  - — SEM
  - — SAM
- Complete optical metallography laboratory
- Computerized mechanical test equipment
- Quenching and deformation dilatometer
- Computers
  - — MICROVAX I
  - — MICROVAX 3500
  - — MASS Comp 5500s
  - — PCs

Materials for Navy's advanced energy systems are being evaluated at high temperatures under fatigue and creep conditions

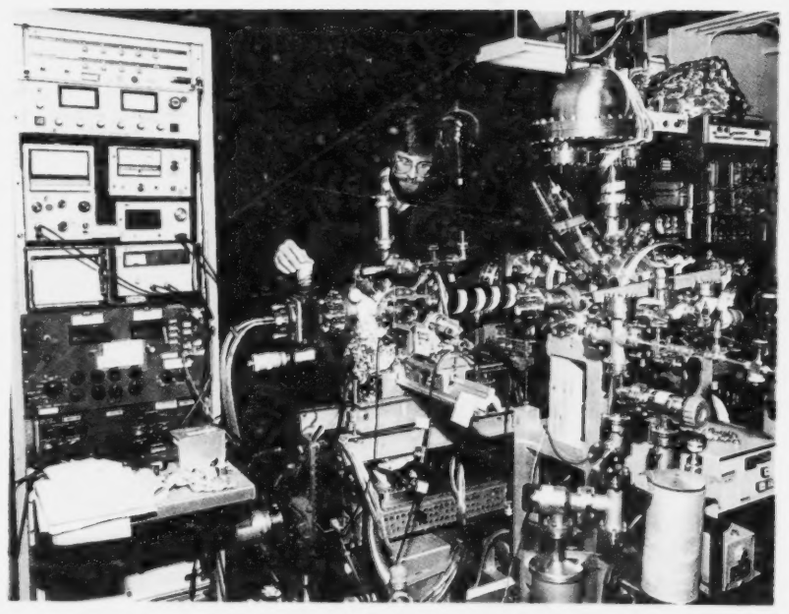
MATERIALS PHYSICS BRANCH

Physicists form the nucleus of this group whose research is wide ranging and involves world-class efforts in magnetism, superconductivity, and the electronic properties of solids. Historically, the branch's programs have focused on metallic systems, but now they include the study of semimetals, semiconductors, and oxides—both magnetic insulators as well as the new class of superconducting cuprates. We study monolayer films through bulk single crystals, classical fermiology through the highly nonlinear response (chaos) observed in ferrites, superconductors, and charge-density wave systems. Typical programs include:

Electronic Properties. Temperature-dependent transport measurements and nonlinear behavior of solids are correlated with other structure and property measurements to establish the basis for understanding and predicting the behavior of metals, semimetals, intercalated semiconductors, and lower dimensional conductors.



Ultrahigh vacuum RF/DC sputtering system used to prepare films of both commercial and oxide superconductors. Inset is a fractal structure synthesized by RF sputtering.



Molecular beam epitaxy unit used for growth of single-crystal magnetic films on semiconductor substrates for electronics applications

Magnetic Properties. A variety of magnetic and spectroscopic techniques are studied to understand how to improve the properties of magnetic materials. These studies have historically focused on bulk magnetic materials and have recently been extended to the study of thin magnetic multilayers.

Superconducting Materials. Superconducting films, bulk materials, and single crystals are prepared and characterized to develop an understanding of their fundamental properties. We use state-of-the-art fabrication facilities and equipment to measure resistivity, magnetization, magnetic susceptibility, critical current density, thermal conductivity, thermopower, specific heat, and surface resistance as functions of temperature and magnetic field. Measurements can be made in temperatures down to 20 millikelvin and fields up to 18 Tesla.

Multilayer Magnetic Materials. Investigations of the properties of single-crystal films and multilayers of magnetic metals and semiconductors grown by molecular-beam epitaxy are studied.

Stuart A. Wolf
Ph.D. in Physics
Rutgers University

"Understanding the properties of materials is the key to both fundamental science and emerging technologies."

Metastable magnetic materials and ultra-thin-layer superlattices are grown and characterized by a host of surface and spin-polarized spectroscopies. Major efforts are directed to those magnetic materials whose growth in single-crystal, thin-film form would not be possible by other techniques.

Applied Magnetics. The properties of magnetic materials in various forms—thin film, bulk or particulate—are developed and improved to meet future Navy needs for high-frequency magnetic devices. Also, we seek to understand the basic physical properties necessary to predict and manipulate these material properties. Several unique experimental techniques exist for these studies.

FACILITIES

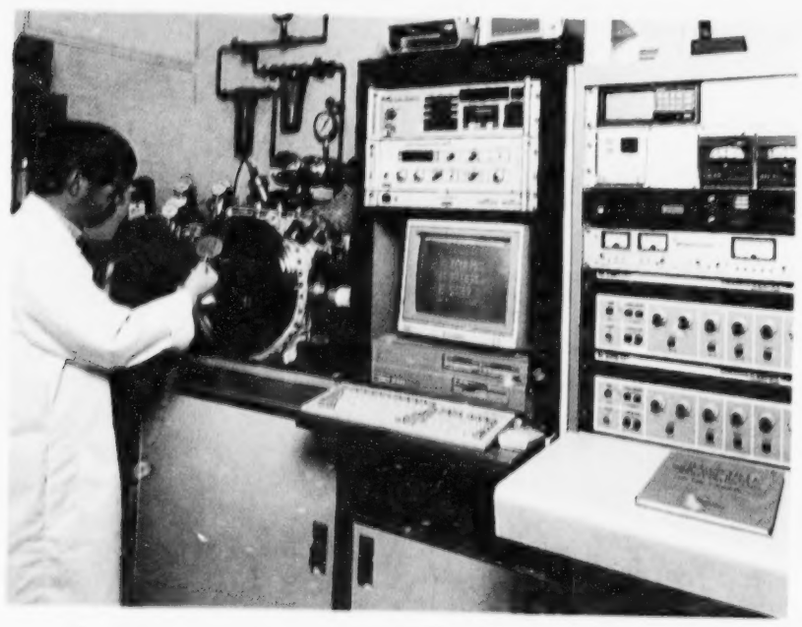
- Deposition
  - — Metal molecular-beam epitaxy systems
  - — Multitarget RF/DC sputtering systems
- Surface analysis
  - — Auger spectroscopy
  - — X-ray and photoemission spectroscopy (XPS) and spin-polarized XPS
  - — Reflection high-energy electron diffraction (RHEED)
  - — Spin-polarized low-energy electron diffraction (SPLEED)
  - — Cyrogenic and high-vacuum scanning tunneling microscopes (STMs)
- Superconductivity and magnetism
  - — Dilution refrigerator 20 millikelvin and 14 Tesla
  - — Superconducting quantum interference device (SQUID) susceptometers
  - — Vibrating-sample magnetometers
  - — Conversion-electron Mossbauer spectrograph
  - — Electron paramagnetic resonance (EPR), ferromagnetic resonance (FMR), and nuclear magnetic resonance (NMR) spectrometers
  - — Closed-cycle refrigerators
  - — High-field, high-resolution torque magnetometry

COMPOSITES AND CERAMICS BRANCH

Santiago C. Sanday
Ph.D. in Engineering
Carnegie-Mellon University

"The full impact of composite and ceramic materials on structure and device performance may be realized only through a vertically integrated research, development, design, engineering, and manufacturing technology program."

The branch conducts basic and applied R&D and engineering studies on ceramic and composite materials for structural and nonstructural applications in various environments under static and cyclic thermal and mechanical loading conditions over a wide range of operating temperatures. Research is focused on the fundamental relationships among composition, composition modulation, interfacial control, microstructure, processing, and composite architecture to obtain specific combinations of properties. Development and engineering efforts address the generation of a technology base for the rational selection or design of materials to be used in advanced naval applications. Schemes to synthesize laboratory quantities of materials are chosen and developed based on their potential for scale-up into industrial manufacturing. Modeling—in closed form or by numerical methods—complements each step of the research, development, synthesis, and engineering of composites and ceramics. Typical programs include:



Dual ion-beam synthesis of metallic multilayered films

Matrix/Fiber Interfaces. Research is directed at understanding interfaces to develop matrix/fiber interphase coatings that minimize interdiffusion at high temperatures and/or accommodate differential expansion during temperature changes.

Multilayered Microstructures. Mechanisms responsible for the observed

supermodulus and superstrength effects are studied in multilayered microstructures.

Nanocomposite Materials. Materials with exceptionally high temperature strength are obtained by embedding high-volume fractions of submicron-size hard particles into ductile metals and alloys. New synthesis methods permit choosing phases that are not subject to the usual thermodynamic limitation of alloying and compound formation.

Damping in Metal Matrix Composites. Emphasis is on composite microstructures development to enhance material-intrinsic damping capacity.

Deformation-Processed Composites. Current efforts are aimed at expanding the temperature range of these materials by understanding the capillary and recrystallization instabilities that lead to property degradation at elevated temperatures.

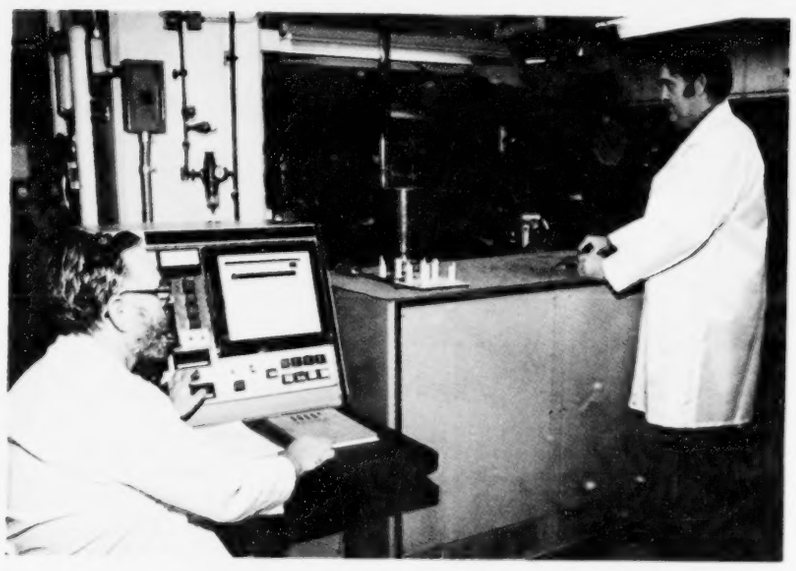
Structural Ceramics. Efforts involve optimizing the mechanical properties of monolithic ceramics and fiber-reinforced ceramics by obtaining desirable material microstructures through the control of processing parameters.

Electronic Ceramics. Ceramics alloys with voids of predetermined size, shape, and distribution are studied to increase the sensitivity of piezoelectric transducers under high pressure and high power density microelectronic substrates.

Thin Films for Electro-optics. Crystallographic alignment of chemically deposited films on silicon surfaces is sought to integrate electro-optic devices with electronic circuits.

FACILITIES

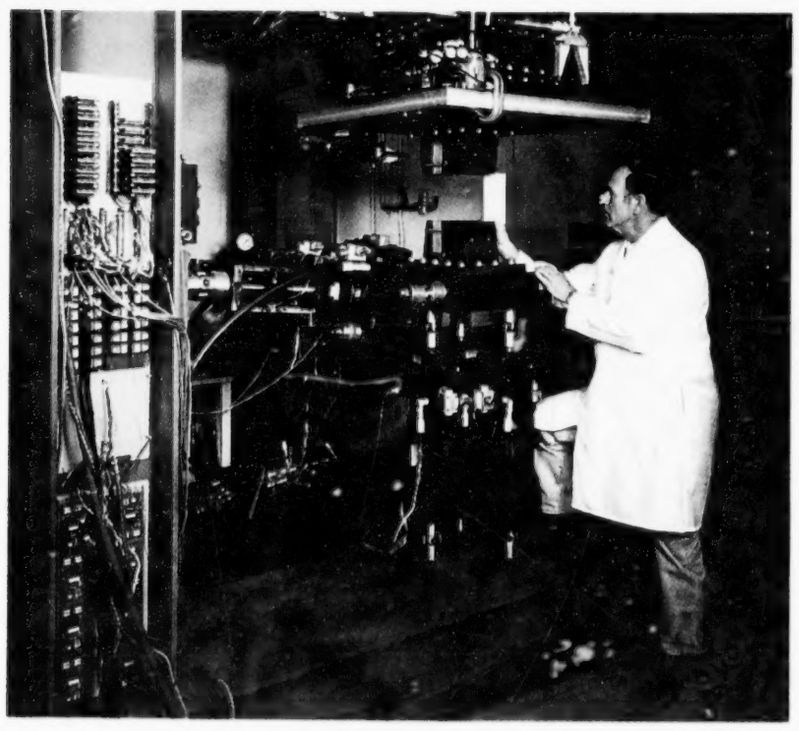
- Multiple target, computer-controlled, fiber coating system
- Dual ion-beam sputtering system
- High-vacuum magnetron sputtering and electron-beam evaporation systems
- Three-source Trimag sputtering system
- Large chamber cold isostatic press
- Hot isostatic press
- Vacuum and air hot presses
- Metal-working equipment
- Piezoelectric-ultrasonic apparatus
- Automated dilatometer
- Highly accurate interferometer
- Wear testers
- Thermal analysis system
- Computer-controlled universal testing machines



Hot isostatic pressing of ceramic or metal powders and ceramic or metal matrix composites

MECHANICS OF MATERIALS BRANCH

Rapid developments in materials technology hold the promise of significant increases in structural performance, reliability, and efficiency. To realize these possibilities, new challenges in experimental measurement, theoretical modeling, and computational simulation must be met.



Large in-plane loader. The facility, which is used to test coupons fabricated from composites, has six degrees of freedom. The computer data acquisition system records and stores 50,000 data points per minute.

This branch brings together individuals from a broad range of disciplines to formulate and address fundamental science and engineering issues. Material response is studied over a broad range of spatial, temporal, and thermal scales to understand how local deformation and energy dissipation processes can be used to produce strong, durable, and reliable structures. At the same time, material composition, structure, and processing issues are examined to identify those features and combinations that best serve structural applications. Research areas include:

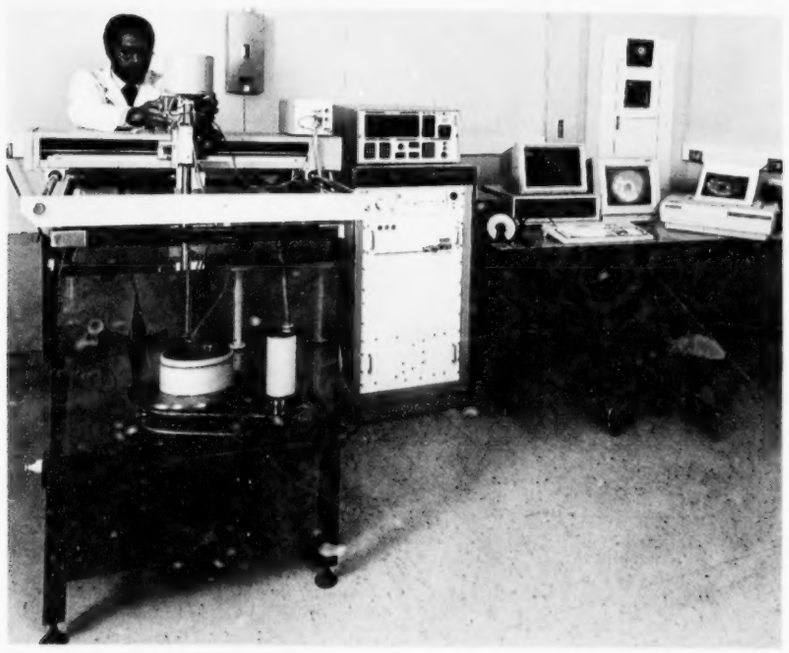
Mechanics of Metallic Materials. Emphasis is placed on constitutive modeling and finite strain characterization; thermomechanical coupling of material damage, lattice, microstructure and continuum parameter relations; quantitative fractography and damage modeling; high strain rate effects; and the mechanics of ductile fracture.

Mechanics of Composite Materials. Current interests are constitutive modeling of anisotropic solids, automated multiaxial damage and energy-dissipation assessment, and material-design-parameter optimization.

Structural-Analysis Methods. Topics of interest include laser-damage assessment, welded-structural integrity, buckling of composite structures, and fluid-structure interaction.

Nondestructive Evaluation Technology. Major concerns are texture and residual stress characterization by ultrasound; defect characterization of welded structures, thick composites, and multilayered components; parallel-processing simulations of wave propagation; and the relationship of defect form to structural function.

Applied Mathematics and Computation. Emphasized are homogenization theory for effective material response, automated theorem proving, computer-controlled experimentation and data analysis, symbolic processing, digital image processing, hypermedia-assisted control of analytical strategies, and unified development of coupled-field theories.



Ultrasonic nondestructive evaluation unit used to inspect materials for tiny flaws or defects

FACILITIES

- MicroVax 3600 computer
- Symbolics computers
- Silicon graphics computer workstations
- Computer-controlled Instron and MTS test machine
- Computer-controlled high-rate Instron test machine
- Computer-controlled in-plane composite loader
- Computer-controlled six degree-of-freedom composite loader
- Automated ultrasonic NDE, continuous-wave and pulse spectroscopy facility
- SQUID magnetometer
- Standard- and high-rate video cameras
- Video image-processing equipment
- Video animation equipment

Corrosion Fatigue. Emphasis is on the effects of microstructure on fatigue crack growth behavior in seawater.

Ripple Load Effects on Stress Corrosion Cracking. Emphasis is on high strength, low alloy (HSLA) steels.

Robert Badaliance
Ph.D. in Applied Mechanics
Lehigh University

"Developments in computational science are re-defining the way that we approach research in mechanics and physics of solids. Experiment and theory, analysis and synthesis, processing and performance, all are heavily impacted by these recent advances."

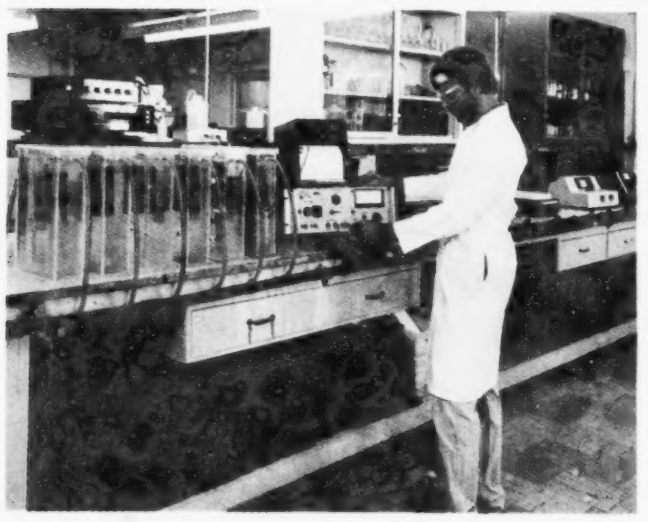
MARINE CORROSION FACILITY

Corrosion protection provides the largest single operational cost saving in the Navy. Therefore, the Marine Corrosion Facility (MCF) was established by NRL in Key West, Florida in 1963. With its prime location and its full complement of personnel and test facilities, it has become a unique facility dedicated to helping the naval community resolve the complex engineering problems associated with materials when they are exposed to a marine environment.

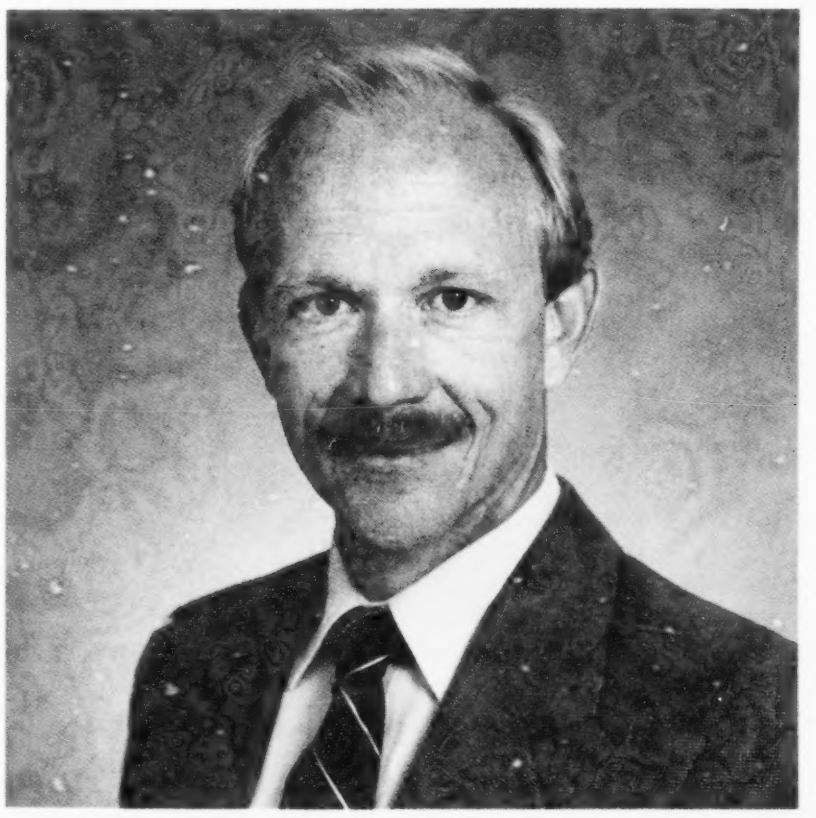
The facility provides the ability to address in a timely manner such issues as current and future performance of materials in or near seawater and provides a long, corporate memory of corrosion issues experienced by the Navy. It receives support in related technical fields from the scientists and engineers at the NRL main site in Washington, DC.

A broad range of research and engineering services are available at the MCF. Typical projects include:

Physical and numerical modeling of cathodic protection for surface ships and submarines.



Electrochemistry laboratory



E. Dail Thomas
M.S. in Materials Engineering
University of Delaware

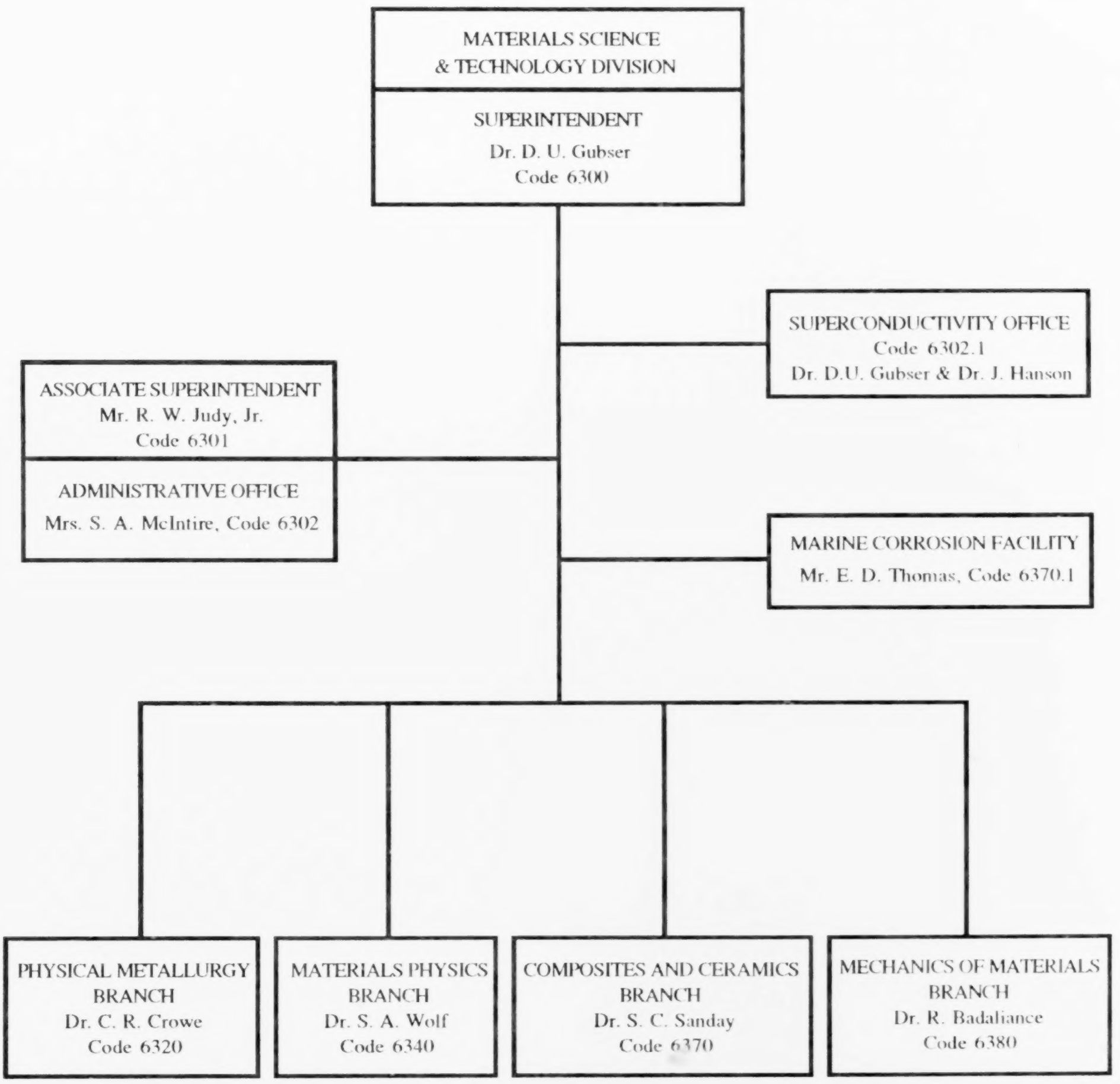
Evaluating materials in flowing natural and chlorinated seawater.

Performing engineering studies on galvanic anode materials.

Determining resistance to fouling of organic coatings and resistance to weathering of coating systems in tropical marine exposure.

FACILITIES

- Low-velocity and quiescent seawater available in flumes and at laboratory benches
- Physical modeling for cathodic protection design
- A laboratory for
  - — chemical analysis
  - — electrochemical testing
  - — mechanical testing
  - — metallography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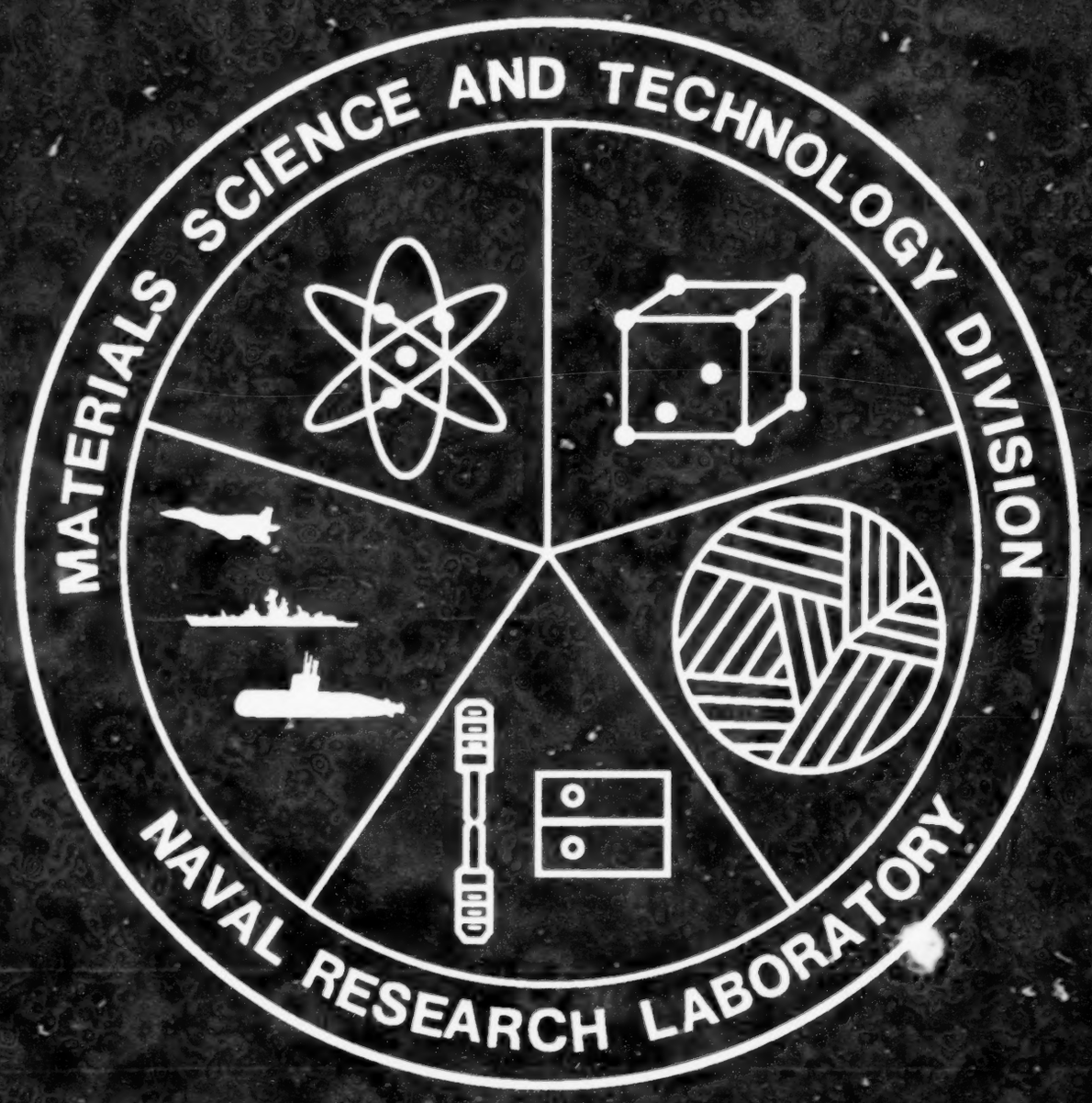

Reviewed and Approved
October 1989

Donald U. Gubser

Superintendent, Materials Science and
Technology Division